Integration of noise in Pavement Management Systems

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Summary

Road administrations use a systematic approach when planning the maintenance of pavements. A Pavement Management System (PM System) is used. Such a System is based on a database and a pavement renewal optimization algorithm where parameters are converted into monetary values that are used in the optimization process. Information about pavement type, age and conditions etc. is stored in the database. The pavements condition is measured every year or less frequent. Parameters like friction, surface texture, evenness and wear and tear are included. The optimization algorithm is used to predict the economical most optimal strategy for renewal of the old pavements. The Danish Road Directorate has conducted a project to develop methods on how noise can be integrated in PM Systems. Part of this has been to select a test road network of a length of 111 km. CPX trailer noise measurements has been performed and stored in a database as noise source data together with the relevant pavement information. Noise mapping in 1 dB intervals has also been performed along this test road network. The noise mapping can be adjusted to the actual measured noise emissions and used as noise exposure information. Using a price on noise exposure expressed as price per dB per dwelling, noise mapping data can be used to predict a yearly cost of the noise along the test road network. A simple acoustic aging model for pavements has been developed on the background of empirical data. The aging model can be used to estimate the increase in noise exposure over the years and this makes it possible to predict the increasing cost of noise. In this way the actual noise from pavements are converted into a cost that can be integrated in a PM System.

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1. Introduction

An important task for road administrations is to maintain and renew the pavements on the road network. In order to do this in a systematic and optimal way a Pavement Management System (PM System) is often used. The central part of a PM System is a database with updated information on all road sections about pavement type, age, conditions, surface texture, and functionalities like friction and unevenness. Noise is usually not included. This database information is continuously updated based on measurements and inspections on the road network. Parameters are converted into monetary values. A PM System also contains am optimization part which can be used to predict where it economically is most efficient to change worn down pavements and apply new road surfaces. The purpose of the project is to develop different methods for implementing the parameter noise into the PM-System of the Danish Road Directorate (DRD), the so called "vejman.dk" system. In vejman.dk all relevant parameters are converted to monetary terms and it is these values that are used in the economical optimization process. Therefore noise needs to "speak" the language of money to be accepted as factor to be integrated.

2. Noise mapping

It is common knowledge that the noise emission from a road pavement depends on many factors like pavement type, maximum aggregate size and the age of the pavement. Noise mapping is in Denmark performed using the Nord2000 prediction method [5, 6]. As a standard reference pavement the Nord2000 uses a dense asphalt concrete with 11 mm maximum aggregate size (AC11). The reference pavement has an age of 8 years which is a reasonable expression of the average age of pavements on state roads in

Denmark. Nord2000 includes corrections for a few other pavement types like SMA8, SMA11 and noise reducing thin layers (called SRS). In this way Nord2000 predicts the average noise level over time at dwellings along roads and this is considered relevant for planning purposes. The Nord2000 noise emission levels for the pavement types included in the method can be seen in Table 1 expressed as CPX levels at 80 km/h. AC11 is often used for noise mapping.

Table 1. Nord2000 noise emission levels expressed as CPX levels at 80 km/h for pavements with an average age of 8 years [1]. "SRS" is noise reducing thin layers.

Pavement type	*SMA11 [dB]*	*AC11 [dB]*	*SMA8 [dB]*	*SRS [dB]*
Nord2000	100.8	100.2	100.1	98.4

In a PM System it would be relevant that the noise mapping reflects the noise exposure at dwellings year by year taking into consideration the actual pavement type and condition, age etc. of the pavement on the road causing noise exposure to given dwellings. In order to investigate how this can be done the following investigations and research have been performed:

1. A test road network of a length of 111 km has been selected and CPX trailer noise measurements performed.
2. CPX noise measurements have been performed on worn down pavements with cracks and loss of aggregates etc.
3. The DRD noise mapping has been correlated to the database of vejman.dk.
4. A simple noise aging model has been developed.

Each of these parts will be presented in shorter sections and in the end a method to integrate noise in PM System using monetary terms will be presented.

An international literature survey was conducted in order to highlight previous projects on different aspects on pavement management and noise [1]. Very few references were retrieved [2, 3 and 4].

3. 111 km test road network

In order to investigate the noise emissions on real roads a 111 km long section of the state road network in northern Zeeland have been selected. This includes urban through roads, rural main roads as well as highways with different types of pavements of different age. CPX noise measurements [7] have been performed with the DRD noise trailer "deciBellA" in the right lane in both driving directions. The average maximum noise level for each 100m road lane section has been reported. An example is shown in Figure 1.

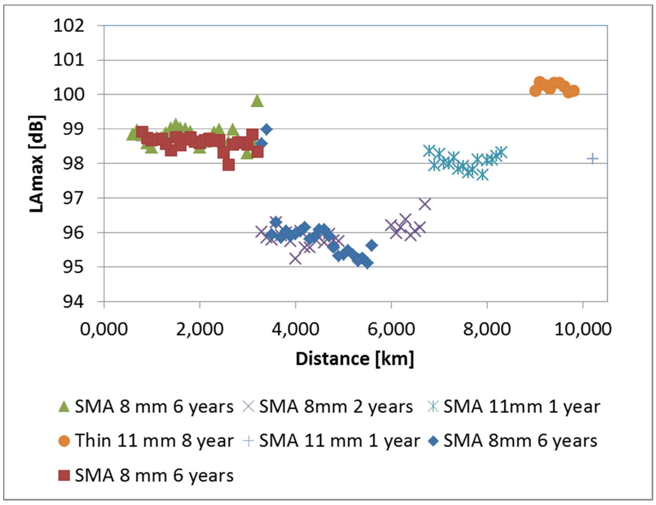

Figure 1. CPX noise levels measured at 80 km/h in two driving direction on 10 km of road section including information on pavement type and age [1].

Figure 2 shows pavement age and noise level for all the measured 100 m pavement sections. It can be seen that the spread in these data for pavements with the same age is quite large and up to 5 dB. This is partly caused by the fact that all pavement types are included in this figure. Linier and logarithmic regression lines are included. The R^2 values are as low as 0.2 and 0.3.

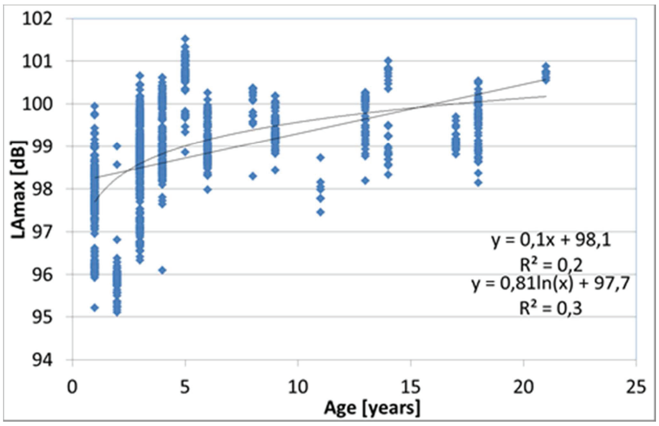

Figure 2. Pavement age and noise level for all the measured 100 m pavement sections. CPX noise levels measured at 80 km/h [1].

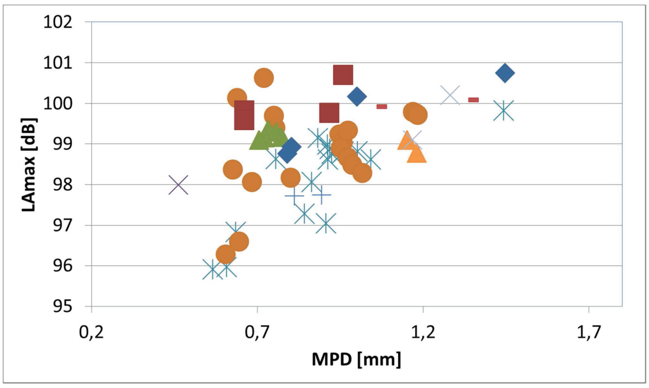

Figure 3. Mean Profile Depth (MPD) and of noise measured for all pavement parcels at the 111 km [1]. Same signature represents same pavement type and aggregate size.

Figure 3 shows the Mean Profile Depth (MPD) as a function of noise measured for all 100 m sections. The data does not show a clear and simple correlation between noise and MPD. The R^2 for a linier regression line is just 0.44.

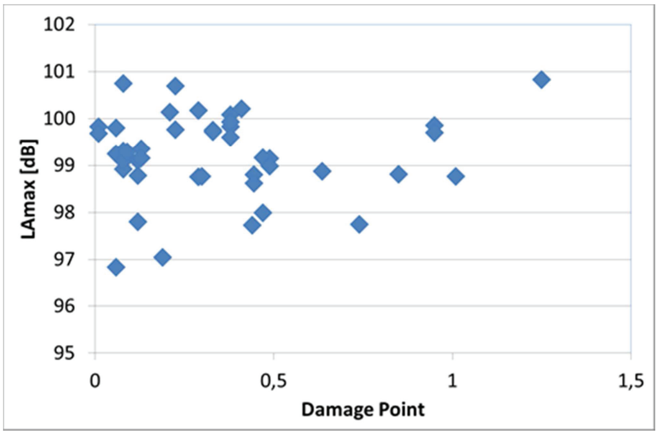

Figure 4. Damage Points and noise for 100 m pavement sections [1].

Visual inspections of the condition of road pavements are performed frequently in Denmark by trained and "calibrated" staff. On this background a "Damage Point" is given to every pavement section expressing the current state of the pavement in relation to structural durability and remaining lifetime. The Damage Point increases as the condition of a pavement gets verse. Figure 4 shows Damage Points and measured noise for many 100 m sections and indicates that there is no correlation between these two parameters.

It would be convenient if a parameter like MPD or Damage Points could be used as a stand in indicator for noise in a PM System, as these parameters are often already available in a database. But this investigation indicates that this will not be possible.

Therefore a representation of noise in vejman.dk cannot be substituted by a representation of MPD or Damage Points instead. The results have also shown that the noise levels of the individual pavements can vary quite a lot between sections with nominally the same pavement type and age. On the background of the measurement results of the 111 km road network it can be concluded that the noise of a specific pavement cannot be predicted with a high precision.

4. Worn down pavements

In order to investigate how high the noise level can become at the end of lifetime of pavements a series of road sections with visible tear and wear and damages like cracks and patches etc. have been found on the road network. CPX noise measurements have been performed.

The results can be seen in Figure 5. The Nord2000 reference level for an 8 year old asphalt concrete is also shown. It is remarkable that the most of the older warn down pavements have the same or even lower noise levels. This indicates that visible damages is not a good indicator for noise levels and that other parameters like the surface texture has a greater influence on the noise levels

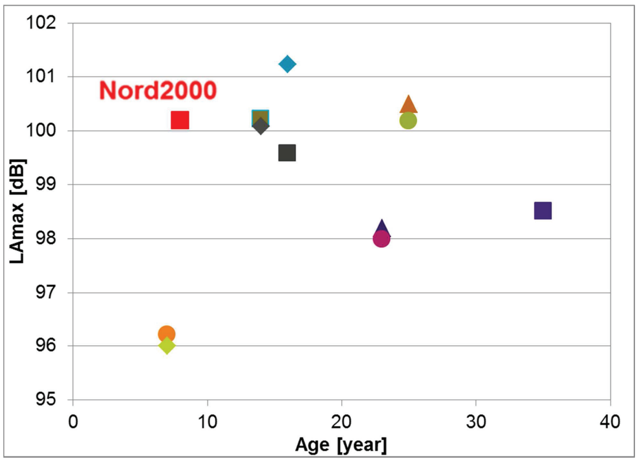

Figure 5. Noise measured on old pavements with visible damages at a speed of 80 km/h [1]. Nord2000 reference level for AC11 is marked by a red dot.

5. Noise aging model

A series of previous Danish and international investigations of the development of pavement noise over time have been evaluated [10, 11, 12, and 13]. There is generally a lack of noise data for pavements at the end of their lifetime. It can be discussed if the noise increase follows a liner or exponential curve [14]. On this background it has been decided to use a simple linear model for the increase of noise over time for different pavement types [1]. On state roads up to 50 % of the noise energy is generated by heavy vehicles.

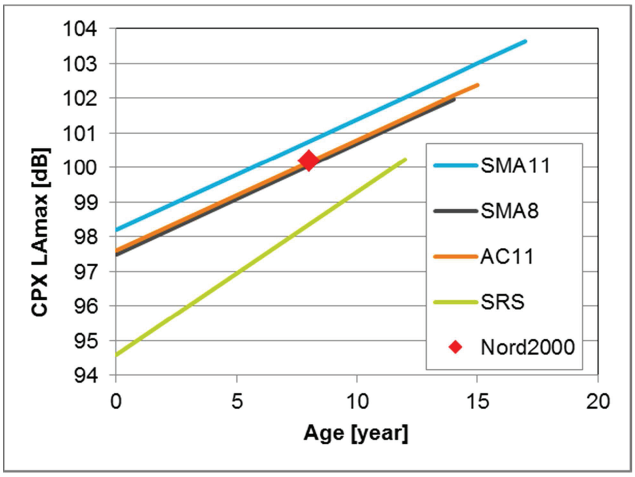

Figure 6. Noise aging model for Danish pavements for a speed of 80 km/h [1]. “SRS” is noise reducing thin layers. Nord2000 reference level for AC11 is marked by a red dot.

On this background it has been decided to develop a model representing an average noise increase per year of passenger cars and heavy vehicles. The input parameters for the model developed are pavement age and pavement type. Information on these two parameters is available in vejman.dk database. The linear model for 80 km/h is presented in Figure 6 for the typical pavements used in Denmark and shown for the average estimated lifetime of such pavement types.

6. Price of noise

The noise exposure on dwellings can be transferred to a value that can be expressed in monetary terms. When performing Environmental Impact Assessment of new road projects in Denmark the Noise Exposure Factor (NEF) is used to evaluate the noise [9]. The Noise Exposure Factor describes the total annoyance from the road traffic on a given road section. When predicting NEF each dwelling is weighted by as factor where the numerical value of the factor is determined by the annoyance caused by the noise level and can be predicted using the below equation.

$$\text{Weighing factor} = 0.01 * 4.22^{0.1(L_{den} - 44)} \quad (1)$$

This means that highly noise exposure dwellings are allocated a higher weight than less noise exposed dwellings. The sum of the weighted number of dwellings on a given road section is predicted and by this the NEF for the road section is found. NEF is only calculated for dwellings with 58 dB or more as 58 dB is the Danish noise guideline. Therefore dwellings that gets a noise reduction so the noise level is less than 58 dB does not “count” in the prediction of NEF.

NEF is used as the basis for economic analysis of noise from road traffic. The cost to society economy can be predicted on the background of the actual price per NEF per year. The price of NEF is derived on the background house price investigations and evaluations of the cost of the health impact of noise [9]. In 2013 the price was 23.787 DKK. per NEF per year [8]. In this way noise can be predicted as a kind of users cost, that can be compared to the users cost of for example uneven roads and in this way noise can be integrated in the pavement optimization procedures.

7. Adjusting noise mapping

The DRD noise mapping from 2012 for the 111 km of state road where the CPX network measurements were performed have been subdivided in 100 m road sections that can be identified in the vejman.dk location identification system. For each of these 100 m road sections the number of noise exposed dwellings over 58 dB (L_{den}) have been predicted in one dB intervals.

Figure 7 shows the noise mapping along a 700 m long section of road through a village as the distribution of 135 dwellings at different noise levels over 58 dB. When using Equation 1 NEF for this road segment can be predicted to 20.0. This represents a yearly cost on noise of 23.787 x 20 = 475,749 D.Kr/year. But the pavements on this road are younger and 3.7 dB less noisy than the Nord2000 AC11 reference pavement. If the noise mapping is adjusted according to the pavements actually on the road, NEF can be predicted to 7.2

representing a yearly cost of noise of 23.787 x 7.2 = 171,266 D.Kr/year.

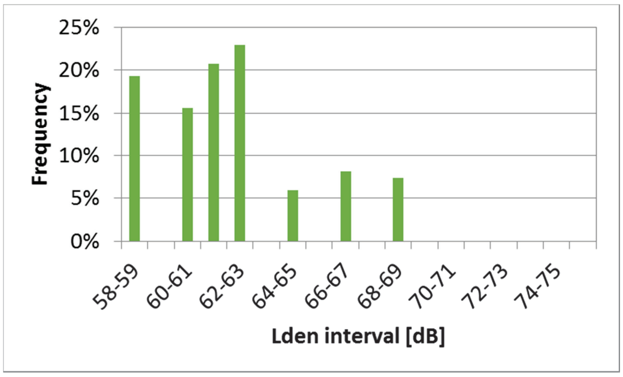

Figure 7. Percentage of 135 dwellings at different noise levels at a 700 m road section [1] based on Nord 2000 predictions.

8. Model solution

For mapping purposes the noise for dwellings along roads is predicted using the method Nord2000. As a starting point the noise from an 8 year old dense asphalt concrete is predicted by the method as an expression of the lifetime average noise level. The results can be presented as number of noise exposed dwellings in 1 dB intervals. If noise shall be included in a PM-System, it will be relevant to be able to predict the number of dwellings that are exposed to different noise levels, taking into consideration the actual pavement that is on a given road section as well as the actual age and condition of this pavement. This can be done in two different ways:

1. CPX noise measurements can be performed and the measurement results can be used to adjust the Nord2000 predicted noise levels from the noise mapping.
2. If CPX measurements are not performed the system can instead be based on table noise levels derived from Nord2000 and data on pavement type and age that can be found in vejman.dk.

8.1 Based on CPX noise measurements

If the system is based on CPX measurements they have to be performed every year in order to directly reflect the actual ongoing increase of noise emission from pavements. If the measurements are not done every year the noise aging model in Figure 6 can be used to adjust the noise levels using the below formulas. For SMA 11, SMA 8 and AC11:

CPX year N = CPX measured + (N–M) x 0.32 (2)

Where M is the year (yyyy) the CPX measurement were carried out and N (yyyy) is the year of prediction.

For the noise reducing SRS pavements:

CPX year N = CPX measured + (N–M) x 0.47 (3)

8.2 Based on Nord2000 table levels

If the system shall be based on table noise levels derived from Nord2000 the below formulas can be used to express the noise as CPX levels at a speed of 80 km/h. For SMA 11, SMA 8 and AC11:

Noise year A = Nord2000-((8-A) x 0.32)) (4)

Where Nord2000 is the noise level found in Table 1 for the given pavement type and A is the pavement age from 0 to 20 years.

For the noise reducing SRS pavements:

Noise year A = 98.4 - ((8-A) x 0.47)) (5)

8.3 Adjusting noise mapping

The noise level at dwellings is as mentioned previously normally predicted using Nord2000 and the 8 year old standard reference AC11 pavement (noise map level). These levels can be adjusted to the noise level of the actual pavements on the road sections in a given year using the below formula:

Real noise = Map level + (CPX level-100.2) (6)

Where "CPX level" is the noise level predicted by one of the above formulas 2 to 5.

When these actual noise levels are predicted for the noise mapping of dwellings along a given road section the yearly cost of the noise exposure along this road can be calculated. This is done by using the predicting the total NEF and multiply this by the 23.787 DKK. per NEF per year as described in Section 6.

In relation to the pavement optimization and prioritizing of new pavements on state and municipal roads, work is done on the pavement repair strategy where the above models for noise can be integrated in the same way as models for user costs caused by for example increasing unevenness. This shall be done in a way where the users (state and municipalities) individually has the possibilities to weigh the users costs in the same way as weighting other factors in the repair strategy. In such a way it will be possible to increase or decrease the influence of noise in the same way as for other parameters used in vejman.dk

9 Conclusions

A method has been established where noise mapping can be adjusted to reflect the noise levels caused by the actual pavements on road sections and the noise can be predicted as a yearly cost.

A next step in this work could be to establish a closed version of the Danish vejman.dk PM System and implement the methods on integration of noise described in this paper. This will make it possible to run some simulations and get experiences on how the system works. These experiences can be used to improve and fine-tune the system.

Acknowledgement

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References

[1] H. Bendtsen et. Al. 2015. Trafikstøj i vejvedligeholdelsessystemer. Muligheder og perspektiver ("Traffic noise in Pavement Management Systems. Possibilities and perspectives" in Danish langue with an English summary). Danish Road Directorate. Report, 2015. See: www.vd.dk

[2] H. Bendtsen og B. Schmidt. Integrating Noise in Pavement Management Systems. Vejdirektoratet, Vejteknisk Institut. Rapport 150, 2007. See: www.vd.dk

[3] Mohammed .A. Alauddin og Susan L. Tighe. Incorporation of Surface Texture, skid resistance and Noise into PM." fra University og Waterloo i Ontarion Canada. 7th International Conference on Managing Pavement Assets (2008)

[4] M. Berengier. F3.3 Detection Systems for Pavement Discontinuities. Overview of technologies and systems to detect pavement discontinuities including assessment of importance to noise reduction. SILENCE report 08.02.2006. See: http://www.silence-ip.org/site/

[5] J. Kragh et. al. User's Guide Nord2000 Road. Delta, SINTEF, SP and VTT

[6] J. Kragh, L. Nøhr Michelsen, J. Fryd, J. Jakobsen. NORD2000 – håndbog. eregning af vejstøj i Danmark. Vejdirektoratet. Rapport 434, 2013. Se: http://www.vd.dk

[7] ISO/CD 11819-2: Acoustics – Measurement of the influence of road surfaces on traffic noise – Part 2: The close-proximity method, 3rd draft, ISO, 2000-12-13

[8] Transporteconomic unit prices at homepage of Transport Institute of the Danish Technical Univercity: http://www.modelcenter.transport.dtu.dk/Publikationer/Transportoekonomiske-Enhedspriser

[9] H. Bendtsen, 2010. Highway noise abatement. Planning tools and Danish examples. Danish Road Directorate, Danish Road Institute. Report 173, 2010. See: www.vd.dk

[10]J. Kragh, B. Andersen, G. Pigasse, 2013. Acoustic ageging of pavement. DVS-DRD joint research programme - super silent traffic. Danish Road Directorate, Report 460, 2013. See: www.vd.dk

[11]H. Bendtsen, Q. Lu, E. Kohler, 2013. Acoustic aging of asphalt pavements - a Californian/Danish comparison. Danish Road Directorate, Danish Road Institute. Report 171, 2013. See: www.vd.dk

[12]H. Bendtsen; B. Andersen; J. Oddershede, 2014. Noise reducing thin layer pavements. Status Report 2010. (in Danish "Støjreducerende tyndlagsbelægninger. Status rapport 2010"). Danish Road Directorate. Report 520, 2014. See: www.vd.dk

[13]J. Kragh, 2008. Road Surfacings - Noise reduction time history. Danish Road Directorate, Danish Road Institute. Report 161, 2008. See: www.vd.dk

[14]L.M. Iversen; J. Kragh, 2014. Acoustic aging rates for pavements estimated by means of regression analysis. Proceedings Forum Acousticum 2014, Krakow